NOVEL POLYPHASE DISTANCE RELAYING SCHEMES

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By
P. GOKUL

to the
DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
DECEMBER, 1982

dedicated to

my

grand father

(Late) Sri M.S. Madhava Rao

CERTIFICATE

This is to certify that the work reported in this thesis entitled 'NOVEL POLYPHASE DISTANCE RELAYING SCHEMES' by P. Gokul has been carried out under my supervision and has not been submitted elsewhere for a degree.

(L.P. Singh)
Professor
Department of Electrical Engineering
Indian Institute of Technology
Kanpur 208016, India.

ACKNOWLEDGEMENTS

It is with a deep sense of gratitude that I express my indebtedness to Dr. L.P. Singh for his exemplary guidance and encouragement throughout the course of my work.

I am also thankful to Messers Desikachar, Hari Bhat, P.G. Poonacha, V.P. Sunnak and A.K. Khellogg for the fruitful and interesting discussions throughout the tenure of my work.

A special word of mention to Mr. C.M. Abraham without whose dedicated and painstaking efforts, the thesis could not have been in the present form.

P. Gokul

ABSTRACT

The present day EHV/UHV transmission systems need a fast, reliable and efficient protective relaying system.

In the past, electromechanical relays were being used. Due to their numerous disadvantages, they were replaced in the beginning by electronic relays and later by solid state relays. The advancements in IC technology have helped in the design of many compact relaying circuits. The advent of programmable equipment has revolutionarised the art of relaying.

A relaying scheme for the protiection of a three-phase transmission line requires 6 measuring units to cater to all possible types of faults.

In an attempt to reduce the number of measuring units polyphase distance relays were proposed.

In the present thesis, a polyphase distance relaying scheme for the protection of transmission lines is proposed. The block diagram and the circuit configurations have been given. The proposed static polyphase distance relaying scheme has been fabricated and tested.

Digital protection schemes for three phase and six phase transmission lines are also proposed. The proposed digital protection schemes have been tested on sample power system networks.

Table of Contents

Chapter One

INTRODUCTION

1.1 MOTIVATION

The art and science of protective relaying in power systems has assumed a greater importance all over the world with the tremendous expansion of interconnected power system networks. There has been a demand for more reliable, efficient and fast acting systems of protection. This has led to the development of static relays and also digital protection schemes, which offer, to some extent a solution to the above mentioned problems.

In the continued development of improved relaying schemes,the major targets have been increased speed and improved reliability. Of these, speed offers the greater economic contribution to the system.

Studies have shown that a given system can transmit larger amount of power without loss of synchronism when short circuits are cleared in a shorter time. With today's static relays and fast acting circuit breakers, it is possible to remove a three phase faults on a transmission line in a maximum of 2 cycles and thus, maximise the systems load transfer capability. Conversely, the system may be designed more economically possibly with fewer lines, or switching stations when faster relays and circuit breakers are used.

Higher speed clearing also reduces burning of line conductors which may otherwise result in eventual conductor failure by subsequent corrossion with resulting loss of service. A second effect of pitted conductors is to increase corona and radio noise, which adversely affect the public communication systems.

The large number of static relays in service since the year 1960 to the present have confirmed the high degree of reliability which can be achieved through conservative design of solid state circuits and complete protection against electrical surges induced from the neighbouring conductors.

In the past O.C. relays were being used for the protection of transmission lines. But owing to its inherent limitations such as, change of balance point with the type of fault, changes in generation, they were replaced by distance relays. Later on many high speed distance relaying schemes with different threshold characteristics were proposed.

A distance relaying scheme for the protection of a 3-phase transmission line requires the use of six measuring units. In an attempt to reduce the number of measuring units, polyphase distance relaying schemes were proposed. A polyphase distance relay is a single unit which is capable of protecting a transmission line against all the types of faults (which are

ten in number for a 3-phase transmission line). These essentially being static devices, have low VA burdens. They have the additional feature of being inherently immune to power swings.

Thus, the polyphase distance relaying schemes, in addition to minimising the number of measuring units, also reduce the circuit complexity, since additional circuitry for inhibiting the relay operation during power swings is avoided. Now, with the advent of programmable equipment, many fast and efficient relaying algorithms have been developed.

1.2 PROBLEM DEFINITION

Development work on static relays started during the year 1945, initially utilizing thermionic tubes. With the advent of transistor and other solid state components during the years 1950-60, the static relay development incorporated these devices. In the initial stages, static circuits were mere substitutes of their electro-mechanical counterparts. In the later stages, new principles have been evolved on hybrid and other unconventional devices and characteristics.

Static circuits have been found to be well suited to the development of polyphase relays giving directional, distance and differential characteristics.

Later, phase and amplitude comparators gave place to instantaneous sampling comparators. Digital and analog computers entered the field of system protection and revolutionarised the concept of relaying.

In the present thesis, a polyphase distance relay based on phase comparison principle is proposed. The relaying scheme has been designed and fabricated.

Schemes for the protection of 3-phase and 6-phase transmission lines using a digital computer have also been proposed. The digital computer programmes have been tested for all possible fault conditions, on a sample system on the DEC-1090 system at IIT Kanpur.

1.3 HISTORICAL TREND

The origin of polyphase distance relays dates back to the years 1954 to 1959, with the introduction of the induction cup type of relay for all phase to phase faults and then extended to the static form for the phase to ground faults.

Sonemann et al proposed a polyphase distance relaying scheme for the protection of transmission lines [1], the main drawback of this relay was its inability to provide protection against single line to ground faults.

As a complement to it, Rockfeller [2] developed a ground distance relay based on amplitude comparison of fault point sequence voltages. Another principle of polyphase distance relay by phase sequence detection of compensated phase voltages, showed narrow operating zone on the complex impedance plane, specially during faults involving ground.

A polyphase distance relaying scheme based on multi-input selective phase comparison was proposed by Choudhuri et al [4] in 1973.

Although the present polyphase distance relaying schemes are successful in application, they suffer from a number of demerits such as, lack of flexibility, duplication of specification effort, lack of adaptability to system changing conditions and exclusion of self testing (in off line and on line) facilities due to complexity and cost.

These disadvantages have resulted in a trend towards the use of programmable equipment in place of hard wired system. There has been enough work in this area and a number of fast and efficient algorithms have been developed.

1.4 SALIENT FEATURES OF THE WORK

The proposed static polyphase distance relaying scheme discussed in this thesis is capable of detecting any type of fault and producing a tripping signal in about half a cycle. It utilizes four 90° transient free phase comparators

based on block average phase comparison principle. Out of the four comparators, one is meant for catering to three phase faults, and the remaining three respond correctly for all single line to ground and all double phase faults with or without ground. The outputs from the four units are fed to a logic 'OR' gate which initiates tripping.

It has been demonstrated in the above scheme that a ground distance relay utilising the shift between the phase to neutral voltages at the relay point and the same voltage properly compensated by line currents flowing through the replica impedances, can be made to respond correctly to both ground and phase faults.

In the proposed digital relaying scheme, a digital computer program capable of detecting all possible types of faults and producing a tripping signal in less than a $\frac{1}{2}$ a cycle has been developed. A quadrilateral threshold characteristic which has been realised in the above scheme, has the following salient features.

1. It is in operative during power swings.
2. It is inherently directional.
3. It is in operative at higher power factors.

1.5 CHAPTERWISE DESCRIPTION

Now, a chapterwise description of the present work is given briefly.

In Chapter 2, the general principle of polyphase distance relays is discussed. It is followed by the theory of the proposed relaying scheme and a description of the experimental circuit. The chapter concludes with the results and discussions.

Chapter 3 deals with the general principles of digital protection. In addition to this, the merits of digital protection and different algorithms for real time calculations of impedance are discussed.

Chapter 4 deals with the theory and mathematical formulation including the algorithm for the digital simulation of the proposed three phase relaying scheme.

A relaying scheme for the protection of a six-phase transmission line is also given in this chapter.

Chapter 5 deals with the findings of the present work and scope for future exploration.

Chapter Two

PROPOSED STATIC POLYPHASE DISTANCE RELAY

2.1 INTRODUCTION

A polyphase distance relay is preferred to single phase distance relays for the protection of transmission lines. The use of a polyphase distance relay reduces considerably the number of relay measuring units required. Further, the polyphase relays are not affected, in general, by power swings, momentary overloads and faults occuring behind the relay location.

Switched relays were the earliest type of polyphase relays proposed. The distance measuring units in these relays are generally connected for phase faults (i.e. Delta voltages and Delta currents) and are switched to star connections when a single line to ground fault occurs. Such relaying scheme could not become popular due to several drawbacks such as complex switching circuits, over reach and under reach.

Later on, polyphase distance relays using the potentials at the relay location and compensating for IZ drop in the line between the relay and the fault, were proposed. The nearest approach to a practical solution was a phase

phase comparator, compensated for line drops and zero sequence components to give the phase to neutral potentials at the fault which generate a zero sine product for a fault at the balance point. But this scheme had the disadvn adisadvantage of under reaching for a balanced 3-phase fault and thus required a second relay to clear such faults.

Amplitude comperators seemed to offer a solution to the above problem. They could use either the phasor quantities in star or sequence quantities but neither of the two could give much economy over single phase relays and the use of sequence quantities introduced some loss in accuracy because of sequence filters. Also, the advantages of using three comparators instead of the six required for single phase relays is more or less cancelled by the cost introduced by the filters and complex circuitry.

Later on, a method involving the determination of phase sequence of the compensated phase voltages was proposed. But it had the following disadvantages :

a) the relay may not operate when there is a high arcing resistance near the balance point,

b) the relay may maloperate due to DC offset present in the fault current,

c) the operating time can be as high as 4 cycles for a fault near the balance point due to high DC offset current.

In the present thesis, a polyphase distance relay based on phase comparison principle of the compensated phase voltages is proposed.

This relay does not have the short comings of the existing polyphase distance relays as mentioned above.

2.2 THEORY OF THE PROPOSED POLYPHASE DISTANCE RELAYING SCHEME

In the proposed scheme, a polyphase distance relay capable of detecting correctly all the single line to ground faults and all the double phase faults with or without ground, by the phase comparison of the line to neutral compensated fault point voltages has been realised. To cater for all the types of faults, four 90° transient free comparators based on block average phase comparison principle [4] has been used. Out of these four comparators, one is meant for catering to three phase faults and the remaining three respond for all single line to ground faults and double phase faults, with or without ground.

The outputs from the four comparators are fed to a logic 'OR' gate which initiates tripping.

Derivation of the input quantities

The line to neutral fault point voltage of any phase 'a' during any type of short circuit and assuming zero fault impedance is given by :

$$V_{fa} = V_{ra} - I_a Z_L$$

where

V_{fa} = compensated phase voltage of phase 'a'

V_{ra} = voltage of P.T. secondary

Z_L = line impedance,

I_a = line current in phase 'a'.

$$V_{fa} = V_{ra} - I_{a1}Z_{L1} - I_{a2}Z_{L2} - I_{ao}Z_{Lo}$$
$$= V_{ra} - (I_a + KI_{ao})Z_{L1}$$

where

$K = n-1$, $n = Z_{Lo}/Z_{L1}$ and assuming $Z_{L1} = Z_{L2}$ for lines.

Hence, the three compensated phase voltages at the relay location will be given by

$$V_x = V_{ra} - (I_a + KI_{ao})Z_R = V_{x1} + V_{x2} + V_{xo}$$

$$V_y = V_{rb} - (I_b + KI_{ao})Z_R = a^2V_{x1} + aV_{x1} + aV_{x2} + V_{xo}$$

$$V_z = V_{rc} - (I_c + KI_{ao})Z_R = aV_{x1} + a^2V_{x2} + V_{xo}$$

where

$Z_{L1} = Z_r$, the replica impedance

V_{x1}, V_{x2} and V_{xo} are the positive, negative and zero sequence components of V_x. respectively.

$$V_{x1} = V_{ra} - I_{a1}Z_R, \quad V_{x2} = V_{ra2} - I_{a2}Z_R$$

$$V_{xo} = V_{rao} - I_{ao}\, nZ_r$$

Fig. 1 gives the circuit diagram for obtaining V_x, V_y, V_z etc.

Experimental Circuit

For the construction of polyphase distance relay, 90° phase comparators using integrated circuits have been taken up.

Relevant literatures [5] show that there are three basic methods, namely,

a) Block instantaneous comparison

b) Pulse comparison

c) Block average comparison, a development of(a).

In the block instantaneous comparison, the duration of polarity coincidence determines the output. The tripping criterion is that the duration of the first coincidence should exceed a specified time, usually one quarter of the power frequency period.

In the pulse comparison method, the polarity of one signal is measured during a short interval in one cycle of the second signal usually, but not necessarily, at the latter's peak.

In the block average comparison method, the duration of polarity coincidence is measured on both the half cycles of the input signals and the average value is determined in an integrating circuit, a trip signal being produced if a

specified average value is maintained for more than a prescribed duration.

In the proposed scheme, block average comparison method is used. The two input quantities of the type jV_x, V_y etc. are compared in a coincidence circuit, in which the duration of polarity coincidence is measured on both the half cycles of the input signals, in order to avoid transient over reach which might occur in (a) and (b) because of the assymetry in one of the signals.

The standard output pulses are positive when jV_x, V_y etc. are of the same polarity and are negative when they are of opposite polarity. The output pulses from the coincidence circuit are fed to a linear integrator, whose output increases linearly when the pulse is positive and falls at the same rate when polarity reverse as shown in Fig. 4.

When the integrator output exceeds some preset value, the level detector sends a tripping signal to the final tripping circuit, but the level detector resets when the integrator output falls below the preset value.

The block average principle is preferred, because, although under steady state, there is no basic difference between the three, but under dynamic conditions, comparators in the categories (a) and (b) are inherently more responsive

to system transients and other spurious bysignals by virtue of their instantaneous operation, and their measuring accuracy can be maintained without sacrificing their speed.

The rise and fall rates are at the designer's disposal, so that, the critical phase angle may be set to any desired value. Both the level detector set and reset levels are critical relation so the total excursion limits of integrator linearity and also to the slope of the output. Considding first the setting, it should atleast exceed a value which would be reached after one quarter of the system periodic time. If this were not so, the output would switch at twice the system frequency, even if the displacement between the input signals was greater than the critical value. The difference between set and reset levels should also exceed this same value in order that cyclic switching does not occur for marginal phase displacements when the net rate of change of integrator is very small. Finally, the upper limit of linearity should not be excessive, otherwise, the reset time will be poor. If all these factors are taken into account, together with the problem of designing a trigger circuit to operate to a specified level, it is found that the optimum level detector setting is 2/3 of the the integrator excursion limit and reset 1/3 of the same limit.The block average comparison

scheme is inherently transient free, with a minimum operating time of 10 ms.

Testing

Due to the nonavailability of a polyphase relay test bench, the relay was tested as a phase comparator by giving two signals, representing the compensated phase voltages and it was found to give a tripping pulse over a band of $\pm 90^{\circ}$.

Chapter Three

DIGITAL PROTECTION OF TRANSMISSION LINES

3.1 INTRODUCTION

The digital protection of a transmission line has attracted much attention from protection engineers in recent years.

Growing interest in the use of microprocessors for protection functions is evident from the number of technical papers decreasing the study of and experimentation with such protection techniques.

The advantages of protective relaying using digital computers are :

a) Flexibility :

A single general purpose hardware base, can be used to obtain a variety of threshold characteristics and other functions with the change of the software programming only.

b) Adaptive capability :

The processor can be programmed to automatically change its behaviour depending upon external circumstances which change with time.

c) Data interface access :

A general purpose digital computer systems can always be equipped with input/ouput ports through which data and control commands are exchanged.

d) Self checking ability :

Unlike conventional relays, a digital processor is by nature a dynamic device and most hardware failures are flogged as soon as they occur by a processor stop. During normal operation, when there is no fault, specific programs can be executed which also test the processing hardware.

3.2 GENERAL PRINCIPLES OF DIGITAL PROTECTION

Although a number of arrangements are possible for application of a digital computer to relaying, a simplified hardware configuration is shown in Fig. 5 as applied for the protection of a EHV transmission line.

An analog input subsystem accepts 3-phase ac quantities from power system through conventional CT's and PT's. All of these quantities are sampled simultaneously at uniform intervals, converted to digital form and transferred to the digital processor. The processor stores organises and makes decisions based on the values of the samples. Its prime purpose is to output a breaker-tripping command when a fault occurs on the protected line. Other secondary

controls and data output may also be provided. Stored in the processor memory, is an elaborate programme, which implements the line protection sensing and logic. At the core of the relaying program, is an algorithm which operates on raw incoming data samples, to provide a meaningful indicator of fault presen as well as its location.

3.3 REAL TIME CALCULATION OF IMPEDANCE

If the computer is fed with the sampled values of voltage and current signals, derived from the line, it will be possible to compute the peak current, peak voltage, phase angle, and impedance in each cycle. It is necessary, for the computer to store the sample values atleast over a period of 1 cycle of the system frequency. With these values, the digital computer computes all the relevant information. With the arrival of the new sample, the first sampled values in the previous ensemble is deleted and the same computation is again made over the present set of samples. This process is continuously repeated by the on-line computer.

The calculation of impedance based on the peak values and the phase angles based on the zero crossings will be erroneous because of the presence of transients in line voltage and current immediately after a fault. A few

methods for the calculation of impedance and phase angle are discussed in the following section.

3.3.1 Impedance calculation based on peak values

Among the sample values of voltage and current over a period of one cycle, the positive and negative peak amplitudes are found and their average magnitude is taken to represent V_{max} or I_{max}.

$$V_{max} = \frac{|V_{peak\ positive}| + |V_{peak\ negative}|}{2}$$

$$I_{max} = \frac{|I_{peak\ positive}| + |I_{peak\ negative}|}{2}$$

$$Z = V_{max}/I_{max}$$

Similarly, the time differences of $V_{peak\ positive}$ and $I_{peak\ positive}$ $(T_{positive})$ and that between $V_{peak\ negative}$ and $I_{peak\ negative}$ $(T_{negative})$ are computed for each cycle. The average of these gives a measure of the phase angle

$$\varphi_{phase} = \left[\frac{T_{positive} + T_{negative}}{2}\right] w$$

where w is the system angular frequency in rad/sec.

These computation are repeated for each cycle of the faulted waveforms.

3.3.2 Impedance calculation using the integrals of voltage and current

If the voltage and current signals are assumed to be sinusoidal

$$v = V_m \sin wt$$

$$i = I_m \sin (wt - \varphi)$$

then the integrals over a period of one cycle of rectified waveforms are given by

$$\int_{\alpha/w}^{2\pi+\alpha/w} V \quad dt = 4V_m$$

$$\int_{\alpha/w}^{(2\pi+\frac{\alpha}{w})} i \quad dt = 4I_m$$

for any α.

The effect of higher frequencies present in the transient waveforms will be almost nullified due to integration. Thus the impedance measured in this way will be more accurate than the one measured from individual samples.

3.3.3 Transmission line protection based on system parameters

This assumes representation of a line by a set of differential equation. The most common modes of a transmission line is described by the following differential equations

$$v = R_i + L\frac{di}{dt} \tag{3.8}$$

The above representation of a transmission line recognizes the D.C. offset as a valid part of the solution and therefore no special features need be implemented to suppress the D.C. osoffset.

A number of algorithms have been suggested to solve equation (3.8) numerically. In 1971, Mcinnes et al. [14] proposed an algorithm for this purpose. It proposed integration over two successive time intervals, so that a sufficient number of equations are obtained to solve 'R' and 'L'. Integral equations are solved numerically using the trapezoidal rule.

The final expressions for R and L take the form

$$R = \frac{(V_{k-1}+V_k)(i_{k-1}-i_{k-2})-(V_{k-1}+V_{k-2})(i_k-i_{k-1})}{(i_{k-1}+i_k)(i_{k-1}-i_{k-2})-(i_{k-1}+i_{k-2})(i_k-i_{k-1})} \tag{3.9}$$

$$L = \frac{h}{2}\;\frac{(V_{k-1}+v_{k-2})(i_{k-1}+i_k)-(V_{k-1}+V_k)(i_{k-1}+i_{k-2})}{(i_{k-1}+i_k)(i_{k-1}-i_{k-2})-(i_{k-1}+i_{k-2})(i_k-i_{k-1})} \tag{3.10}$$

where 'v' and 'i' are instantaneous values of voltage and current, 'K' is the instant and 'h', the time interval.

However, it should be noted that there are several problems, associated with the characteristics of actual transmission lines which are not accounted in eqn. (3.8). This equation assumes perfectly transposed lines and neither the shunt capacitance nor the series compensation is considered.

The fault resistance and effect of power flow on the line at the moment of a fault is also not considered. The data window is one cycle.

In 1975, Ranjbar et al. [8] developed another technique which relates appropriate integration intervals of equation (3.8) to the particular harmonics, that are selected for removal. The sampling rate is related as a multiple of the order of the harmonic to be removed, which makes the procedure quite restricted by the sampling rate selection and accuracy.

3.3.4 Transmission line protection based on fundamental frequency signals

This relies on the theory of orthogonal transforms [15]. The most widely used in the fourier transform theory which utilizes the set of sine and cosine functions as a sum of combinations of the functions from the derived orthogonal

set. Basic properties of the fourier transform can be used to extract any particular frequency component from the incoming signal. In the case of the continuous functions, numerical approximation is done to obtain a digital solution.

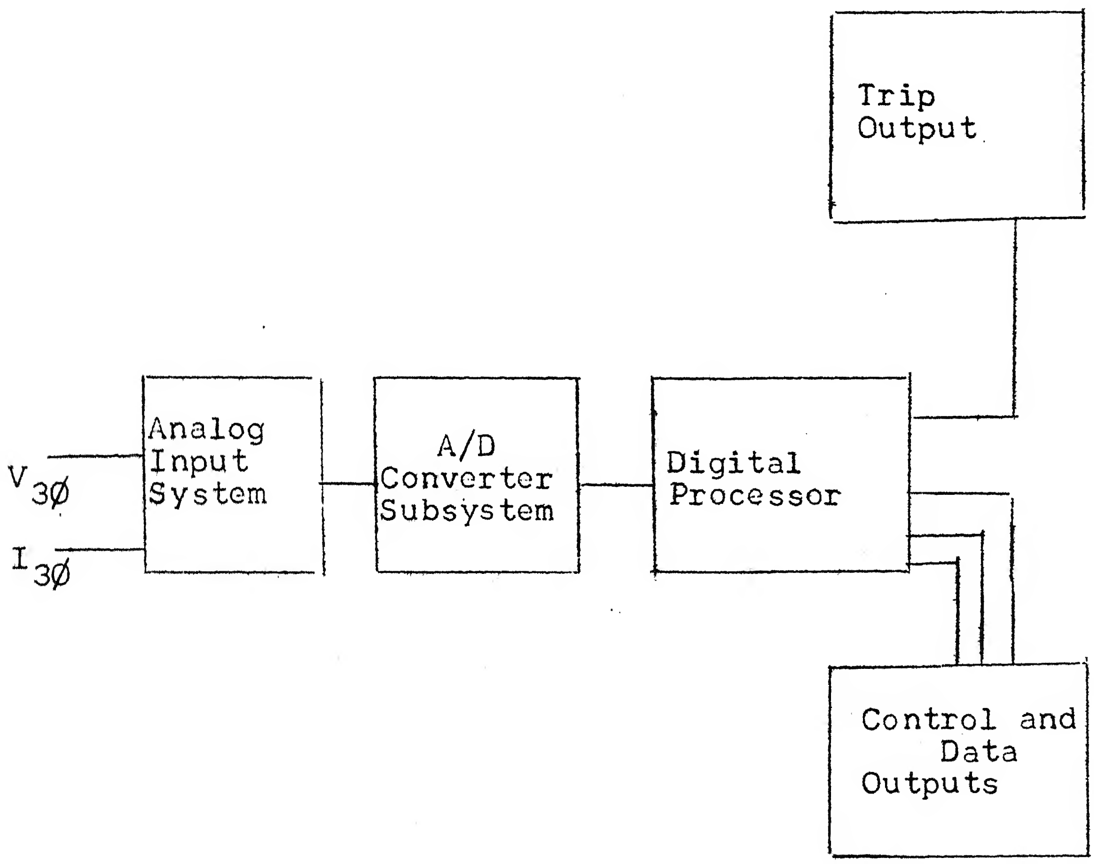


Fig. 5 Simplified Hardware Configuration

3.3.5 Fourier analysis method

In this method, the ensemble of samples over a period of one cycle is assumed to repeat periodically and fourier analysis is performed on the ensemble of samples. The amplitude and phase angle of the fundamental component is obtained as follows :

$$a_1 = X/2\ (f_o + 2f_1 \cos X + 2f_2 \cos 2X + \cdots + f_m \cos mx)$$

$$b_1 = X/2\ (2f_1 \sin X + 2f_2 \sin 2X + \cdots 2f_{m-1} \sin(m-1)X)$$

where $f_o, f_1 \ldots f_m$ are sampled values of input signal over a period of one cycle and X is the sampling interval given by $2\pi/m$. The factors cox X, sin X, ..., cos mx, sin(m-1)X are constants and can be calculated and stored in the memory apriori as weighting functions on the sample values. The fundamental quantity is given by

$$f_1(t) = \overline{\sqrt{a_1^2 + b_1^2}} \quad \sin(wt + \tan^{-1} \frac{a_1}{b_1})$$

If this computation is made for both voltage and current, the impedance and the phase angle can be evaluated.

3.3.6 PREDICTIVE CALCULATION OF PEAK VALUES

In this method, the peak values of the voltage and current waveforms are calculated from each sample.

If $v = V_m \sin wt$

.then

$$V_m = \sqrt{v^2 + (v'/w)^2}$$

and

$$I_m = \sqrt{i^2 + (i'/w)^2}$$

where v and i are the voltage and current samples and v' and i' are their time derivatives. These derivatives are computed numerically.

The phase angle is given by

$$\varphi = [\tan^{-1} \frac{wi}{i'} - \tan^{-1} \frac{wv}{v'}]$$

Out of the above mentioned methods, the fourier analysis method yields the best result, but it requires atleast a full cycle of samples of line voltages and currents immediately after the fault.

In the proposed relaying scheme, the predictive calculation of peak values is used since it requires just 3 samples to determine the peak values of voltage and currents if the central difference theorem of differentiation is used and only two samples if the backward difference theorem is used.

Chapter Four

PROPOSED DIGITAL PROTECTION SCHEMES

4.1 INTRODUCTION

In the proposed relaying scheme a three phase relay with quadrilateral threshold characteristics has been simulated. A digital computer can be used to implement this feature on a practical system. The relay might prove its utility for on-line protection of present day EHV systems.

4.2 THEORY

The principle underlying this scheme is the detection of disturbances, i.e. faults, classification of the type of fault (i.e. phase or ground) and generation of ausuitable single phase set of relaying quantities such as voltage and current which are subsequently used for impedance calculation.

Three line to ground voltages and three line currents are scanned sequentially by subroutine 'SAMP'. Computation of zero sequence current and voltage is interleaved with the scanning and the subroutine 'SAMP' stores these eight quantities, each time it is called for.

A counter, such as COUR for Red; COUY for yellow and COUB for Blue is assigned to each phase voltage.

The voltage samples in each of the phases are compared with the corresponding sample in the previous cycle by COMP. If the values differ in excess of a tolerance TOLV, the counter for that particular phase is incremented. If any of the counters exceeds a value CEV, the system enters into the fault detection mode. On the other hand, if the difference between two voltage samples found by the above comparison is less than TOLV, the counter for the corresponding phase is decremented, if it is not already zero.

When atleast one of the counters, COUR, COUY, COUB has a value equal to 4, the system enters into fault detection subroutines.

4.3 CLASSIFICATION OF TYPE OF FAULT

This is done by subroutines FTYPE and SELCT. The aim of these subroutines is to determine which two of the following

1. Red phase,
2. Yellow phase,
3. Blue phase,
4. Ground.

are involved in the fault and to derive equivalent single phase relaying quantity.

A counter for zero sequence voltage CZSG is used to determine if a fault detected involves ground. The last five

zero sequence voltage samples are compared and for each value exceeding a specified tolerance TOLZ, the counter CZSG is incremented. If the value of CZSG is atleast 4, it indicates that ground is involved in the fault. Subroutine SELECT determines whether any of the red, yellow or blue phases with or without ground is involved in the fault on the basis of the value of these counters.

If a counter has a value 4, then the phase it represents is considered to be involved in the fault. If the counter has a value 2 or 3, the result is undetermined. The main aim of SELECT is to determine two of the counters for subsequent use, i.e. if a RYG fault occurs, it would be sufficient to treat it as RY, RG or YG fault but in any case only two of the red, yellow or blue phase or ground need be considered as being involved in the fault. The red, yellow or blue phase counters of the same value as the ground counter are to be selected in preference to it (i.e. ground), since subsequent impedance calculations are more accurate, i.e., it is preferable to calculate a RYG fault as an RY fault rather than RG or YG fault. In case of a single line to ground,fault, zero sequence compensated current is used for subsequent impedance calculation.

4.4 MATHEMATICAL FORMULATION FOR IMPEDANCE CALCULATION

In the present scheme, it is proposed tow rwork with delta quantities for phase faults and phase voltages and zero sequence compensated current for ground faults because point in this case does not shift due to different type of faults.

The method of calculation of line impedance [5] involves the predictive calculation of peak current and peak voltage, the impedance being determined by division of peak voltage by peak current. A digital computer sampling a sinusoidal waveform, can determine the peak values as they occur.

However, it is necessary in the interest of time to determine the peak values before their occurrence, i.e. to predict the peak value of the waveform from any given sample.

Let v be the voltage sample at any instant, and V_{pk} the peak voltage.

Since it is not proposed to synchronise the sampling to the sinusoidal, the value of sin wt is also unknown.

Let $v = V_{pk} \sin wt$ (4.1)

Differentiating (4.1) we get,

$$v' = w\, V_{pk} \cos wt \qquad (4.2)$$

The various numerical methods for differentiation are given in Appendix III. Central difference method, being the best

from the point of view of accuracy, is being used.

From eqns. (4.2) we get,

$$\frac{v'}{w} = V_{pk} \cos wt \tag{4.3}$$

Squaring (4.1), (4.2) and adding, we get,

$$(v'/w)^2 + (v)^2 = V_{pk}^2 [\cos^2 wt + \sin^2 wt]$$

$$V_{pk}^2 = (v'/w)^2 + (v)^2 \tag{4.4}$$

Similarly peak value of sinusoidal current is,

$$I_{pk}^2 = (i'/w)^2 + i^2 \tag{4.5}$$

Dividing, equation (4.1) by (4.3), we get

$$\frac{vw}{v'} = \frac{V_{pk} \sin wt}{V_{pk} \cos wt}$$

$$\tan wt = \frac{vw}{v'}$$

$$wt = \tan^{-1} [\frac{vw}{v'}]$$

Thus point on cycle of voltage sample,

$$V_\theta = \text{arc } \tan(\frac{vw}{v'}) \tag{4.6}$$

Similarly, the point on cycle of a current sample,

$$I_\theta = \text{arc } \tan(\frac{wi}{i'}) \tag{4.7}$$

Impedance modulus by use of eqn. (4.4) and (4.5) is,

$$Z^2 = \frac{V_{pk}^2}{I_{pk}^2} \tag{4.8}$$

Impedance phase angle is

$$Z_\theta = I_\theta - V_\theta$$

$$= \arc\tan(\frac{wi}{i'}) - \arc\tan(\frac{wv}{v'}) \tag{4.9}$$

Resistance 'R' and reactance 'X' upto the fault point is calculated from Z and Z_θ. The flow chart for the proposed relaying scheme is given in Fig. 6.

4.5 RESULTS

The proposed three phase relaying scheme has been tested on a sample power system network [8], the details of which are given in Appendix II for different types of faults.

In the present scheme, a quadrilateral characteristic has been realised. This scheme possesses the following features :

a) It is immune to power swing

b) It has inherent directional feature

c) The characteristic can be varied by changing the slopes at the instant relay starts

d) It possesses a very high degree of sensitivity, reliability and is fast in operation.

The result of the test is entered in the Table 1. It has been found that the predicted value of the peak voltage and current for all types of fufaults, is accurate to within -0.01818 to 0.3083 percent and 0.4386 percent respectively. The Z modulus is accurate within -0.45 to 0.256 percent and the argument of Z to within 0.328 percent.

The time required for relay operation is determined by four considerations as shown.

Firstly, four samples are required for detection of occurrence of a disturbance. Secondly, seven samples are required for impedance calculations, these may include those required for detection of fault. Thirdly, the impedance calculation itself will take an additional time, and fourthly, the calculation of R and X after calculation of impedance, requires a finite time.

The proposed relaying scheme which is a compact unit for the protection for a 3-phase transmission line is also capable of detecting the location of any type of fault on the line.

The operating time of the relay was found to be 6 ms which is less than $\frac{1}{2}$ a cycle.

4.6 PROTECTION OF SIX PHASE TRANSMISSION LINES

4.6.1 Introduction

One of the most important items in applying the six-phase alternative in transmission planning is the design of an adequate protective scheme.

In a six-phase system, the number of fault types is much greater than that of a 3-phase system. The fact that there are six phases, each subjected to a different voltage, and a neutral in a six-phase system, makes the number of fault types much greater than for the three-phase system. Out of the 120 possible combinations in a six-phase system, there are 23 combinations with distict fault levels and phase interconnections.

Consider line to line faults that do not involve ground. The current magnitude and circuit assymmetry for a fault on phases a and b is the same as that on b and c and so on. Therefore, the 15 two phase fault combinations reduce to 3 significant combinations. These are ;

1) faults between phases 60^{o} apart, e.g. a to b
2) faults between phases 120^{o} apart, e.g. a to c,
3) faults between phases 180^{o} apart, e.g. a to d.

Similarly, the analysis for all faults can be confined to the 23 significant combinations. In the case of a 3-phase system, there are only 5 significant fault types.

4.6.2 Proposed protection scheme for a 6-phase transmission line

The proposed 3-phase digital protection scheme, in the previous section is extended for a 6-phase system; the only difference being in the number of counters, (seven counters COU1, COU2, COU3, COU', COU5, COU6, for the six phases and COUG for the zero sequence voltage) and the type of characteristic realized (plane impedance characteristic in the present case). Explanations given in the previous sections hold good for the present scheme also.

4.6.3 Classification of the type of fault

This is done by subroutines FTYPE and SELCT, The aim of these subroutines is to determine which two of the phases or ground are involved in a fault and to derive equivalent single phase relaying quantity.

If a counter has a value 4, then the phase it represents is considered to be involved in the fault. If the counter has a value 2 or 3, the result is undetermined. The main aim of SELCT, is to determine two of the counters for subsequent use, i.e., if a 1-2-3-G fault occurs, it would be sufficient to treat it as 1-2, 2-3, 3-1, 1-G, 2-G or 3-G but in any case, only two of the six phases or ground need be considered as being involved in the fault. The six-phase counters are to be selected in preference to the zero sequence counter, since subsequent impedance calculations

are more accurate, i.e. it is preferable to calculate a 1-2-3-4-G fault as a 1-2, 2-3, 3-4, 4-1, etc. fault rather than 1-G, 2-G, fault. In case of a single line to ground fault, tzero sequence compensated current is used for subsequent impedance calculation.

4.6.4 Results

The proposed six phase relaying scheme has been tested on a sample system network, the details of which are given in Appendix II., for different types of faults. The results of the test are entered in Table 2. During the test, it was observed that all the faults were detected satisfactorily i.e. in no case did the programme falsely indicate the involvement of the six phases and ground in a fault.

It has been found from the test that for all the types of faults that the magnitudes of peak voltage and current are accurate to within 0.19506 percent and 0.17832 percent respectively. It has also been found that the impedance magnitude is accurate to within $\pm$ 0.087 percent and the argument of the impedance to within -2.41 percent to 0.3695 percent.

The proposed relaying scheme, which has been tested on the DEC-1090 computer system at IIT/Kanpur is a compact unit for the protection of a 6-phase transmission line.

The operating time of the relay was found to be 6 ms which is less than $\frac{1}{2}$ a cycle.

CHAPTER 5

CONCLUSIONS

The present work proposes protection schemes for both three phase and six phase transmission lines.

The proposed polyphase distance relay offers protection against all types of faults likely to occur on a three phase transmission line.

By the use of transient free 90° phase comparator based on block average phase comparison scheme and with simple circuits using ICs, a polyphase distance relay has been developed. The proposed static relay has been designed, fabricated and tested.

The relay has the following advantages :

1. It is not effected by arcing resistance
2. Since, in the 90° phase comparators, the duration of polarity coincidence is measured on both the half cycles of input signals, the over reach in the relay is minimised, which may otherwise occur due to d.c. offset in the current waveform.
3. The circuit is simple and devoid of any complex switching elements.

The operating time of the relay has been found to be about a half a cycle.

The proposed polyphase digital protection scheme, in addition to responding correctly for all the types of faults, also possesses the most desired threshold characteristics namely the quadrilateral characteristics. It is a flexible scheme which upon detection of a fault selects the phases involved and chooses the appropriate set of relaying currents and voltages for subsequent impedance calculations.

The digital computer program computes the impedance to a reasonable accuracy, this is in spite of considering only the first term in the expression for numerical differentiation. Even better accuracies can be realized by considering a few more terms in the above expression.

The proposed digital computer program has been tested in the DEC 1090 system, which showed a minimum operating time of about 6 ms which is less than $\frac{1}{2}$ a cycle for all types of faults.

The six-phase protective relaying scheme developed is capable of detecting all possible types of faults on a six-phase transmission line. Even in the present scheme the impedance computation was within reasonable accuracy.

The proposed scheme demonstrates a method for real time calculation of impedance for a six-phase transmission line. Upon computation of impedance, any complicated threshold characteristics can be easily realised as in the three-phase scheme.

The operating time of the relay was also found to be less than $\frac{1}{2}$ a cycle.

Scope for further work in this area

The digital computer based relaying programme for the protection of three-phase generators and bus bars can be developed.

A microprocessor based scheme for the protection of three-phase to six-phase transformers and buses can be developed.

The computer application for on-line protection may lead to an overall computer control of power system networks in which a central computer would perform all the functions such as monitoring, control and protection.

Table 1 (Three phase system)

Sl. No.	Type of fault	Actual peak voltage	Predicted peak current	Actual peak current	Predicted peak current
1	LG	0.89	0.88875	1.5081	1.502
2	LL	1.265	1.26111	3.3738	3.372
3	LLG	1.265	1.2611	3.3738	3.372
4	LLL	1.265	1.26523	3.3738	3.359

Type of fault	Actual impedance (p.u.)		measured impedance		Error in impedance measurement (percent)	
	Magnitude	Phase (degrees)	Magnitude	Phase (degree)	Magnitude	Phase
LG	0.375	79.7235	0.37231	73.7	0.071	0.75
LL	0.375	79.7235	0.37404	79.5	0.256	0.328
LLG	0.375	79.7235	0.37404	79.5	0.256	0.328
LLL	0.375	79.7235	0.37404	79.7	0.45	0.003

Table 2 (Six phase system)

Type of fault	Actual peak voltage (p.u.)	Predicted peak voltage (p.u.)	Actual peak current (p.u.)	Measured peak current (p.u.)
LG	0.362	0.36132	14.44	14.389
LL	0.391	0.39044	33.023	32.907
LLG	0.391	0.39044	33.023	32.907
LLL	0.339	0.3383	28.599	28.548
LLLG	0.339	0.3383	28.599	28.548
LLLL	0.196	0.19506	16.512	16,466
LLLLG	0.196	0.19506	16.512	16.466
LLLLL	0.196	0.19506	16.512	16.466
LLLLLG	0.196	0.19506	16.512	16.466
LLLLLL	0.196	0.19506	16.512	16.466

Type of fault	Actual impedance (pu)		Measured impedance (pu)		Error in impedance measurement (percent)	
	Magnitude	Phase (degrees)	Magnitude	Phase (degrees)	Magnitude	Phase
LG	0.0118456	78.3106	0.01186	80.2	0.087	-2.41
LL	0.0118456	78.3106	0.01186	78.5	0.0879	0.241
LLG	0.0118456	78.3106	0.01186	78.5	0.0879	0.241
LLL	0.0118456	78.3106	0.01184	78.1	0.0472	0.2689
LLLG	0.0118456	78.3106	0.01184	78.6	0.0472	0.2689
LLLL	0.0118456	78.3106	0.01185	78.6	0.0372	-0.3695
LLLLG	0.0118456	78.3106	0.01185	78.6	0.0372	-0.3695
LLLLL	0.0118456	78.3106	0.01185	78.6	0.0372	-0.3695
LLLLLG	0.0118456	78.3106	0.01185	78.6	0.0372	-0.3695
LLLLLL	0.0118456	78.3106	0.01185	78.6	0.0372	-0.3695

REFERENCES

1. Sonemann, W.K. and Lensner, H.W., 'Compensator distance relaying-I, General Principles of Operation', AIEE Trans., 1958, vol.77, pp. 372-82.

2. Rockfeller, G.D., 'Zone packed ground distance relay-I', Principle of Operation', IEEE Trans., 1966, vol.O PAS 85, pp 1021-44.

3. Bhattacharya, D., Basu, S.K., Bose, K.P. and Patra, S.P., 'A static polyphase distance relay', IEEE Trans., vol. PAS 91, May/June, 1972.

4. Choudhary, S., Basu, S.K. and Patra, S.P., 'Polyphase ground distance relaying by phase coincidence princpile', Trans. Paper presented at IEE, Summer meeting, 1972, Paper No. 172, 428-1.

5. Jackson, L. Patrickson, J.B. Wedepohl, L.M., 'Distance Protection: Optimum dynamic design of static relay comparators', Proc. IEEE, vol.115, Feb. 1968, p. 280.

6. Man , B.J. and Morrison, I.F., 'Digital calculation of impedance - for transmission line protection', Trans. IEEE, PAS-90, No.1, Jan./Feb., 1971, pp. 270-279.

7. Man , B.J. and Morrison, I.F., 'Relaying a three phase transmission line with a digital computer', Trans. IEEE PAS-90,,No.2, March/April, 1971, pp. 742-750.

8. Ranjbar, A.M. and Corey, B.M., 'Improved method for the protection of high voltage transmission line', Trans. IEEE, PAS-94, No.2, March/April, 1975, pp 544-550.

9. MCinnes, A.D. and Morrison I.F., 'Real time calculation of resistance and reactance for transmission line protection by a digital computer', Trans. Inst. Engg. Australia, EE7 (1971), pp 16-23.

10. Hope, G.S. and Umamaheswarn, 'Sampling for computer protection of transmission lines', IEEE Trans., PAS-93, (1974), pp 1522-1534.

11. Tirupathiah G, Varshney, A., Singh, L.P., 'On line digital protection using microcomputer - a centralized approach', National Conference on Planning, Operation and Control of large scale power system, June 1982 at Annamalai University, Tamil Nadu.

12. Bhatt, N.B., Venkata, S.S., Guyker, W.C., and Boot,W.H., 'Six phase (multi-phase) power transmission systems: Fault analysis', IEEE Trans., 1977, vol. PAS-96, No.3, May/June 1977, pp 758-767.

13. Shri Nivas Tiwari, 'Mathematical analysis and modelling of six-phase (multi-phase) power systems - Ph.D. thesis submitted in IIT Kanpur (June, 1982).

14. Nanda, S.P., M.Tech. Thesis submitted in IIT Kanpur (July 1980).

15. Rao, T.S.M., 'Power system protection - static relays', Tata McGraw-Hill, New Delhi.

16. Warrington, A.R., 'Protective relays - their theories and practice', Chapmann and Hall Ltd., New York.

APPENDIX I

Transmission line data [8] which is used for testing the proposed protection scheme (3-phase).

Base = 230 KV, 1000 MVA

Length of line = 300 miles.

Line parameters :

Positive sequence reactance = $j0.123\times10^{-2}$ pu/mile

Positive sequence resistance= 0.223×10^{-3} pu/mile

Zero sequence resistance = 1.226×10^{-3} pu/mile

Zero sequence reactance = $j0.32\times10^{-3}$ pu/mile

Positive sequence capacitive reactance = $-j420$ pu/mile

Zero sequence capacitive reactance = $-j714$ pu/mile.

APPENDIX II

Transmission line data which is used for testing the proposed six-phase protection scheme.

Base 100 MVA/phase

Transmission line data

Positive sequence impedance = 0.0024 + j0.0116 p.u.

Zero sequence impedance = 0.0141 + j0.0901 p.u.

APPENDIX II

DIFFERENTIATION FORMULAE

The basic central difference expression for the derivative [2]

$$hy'_k = (\mu\delta - \tfrac{1}{6}\mu\,\delta^3 + \tfrac{1}{30}\,\mu\,\delta^5)y_k \qquad \text{(AII.1)}$$

where ∇, μ and δ are the standard notations for the operations of backward differing, central differencing and averaging respectively and h is step size, and y stands for v or i.

Using the first term only

$$h\,y'_k = \tfrac{1}{2}\,(y_{k+1} - y_{k-1}) \qquad \text{(AII.2)}$$

and with a second-term

$$hy'_k = -\tfrac{1}{12}\,(y_{k+2} + \tfrac{2}{3}\,y_{k+1} - \tfrac{2}{3}\,y_{k-1} + \tfrac{1}{12}\,y_{k-2}) \qquad \text{(AII.3)}$$

For backward differences

$$hy'_k = (\nabla - \tfrac{1}{2}\nabla^2 - \ldots)y_k \qquad \text{(AII.4)}$$

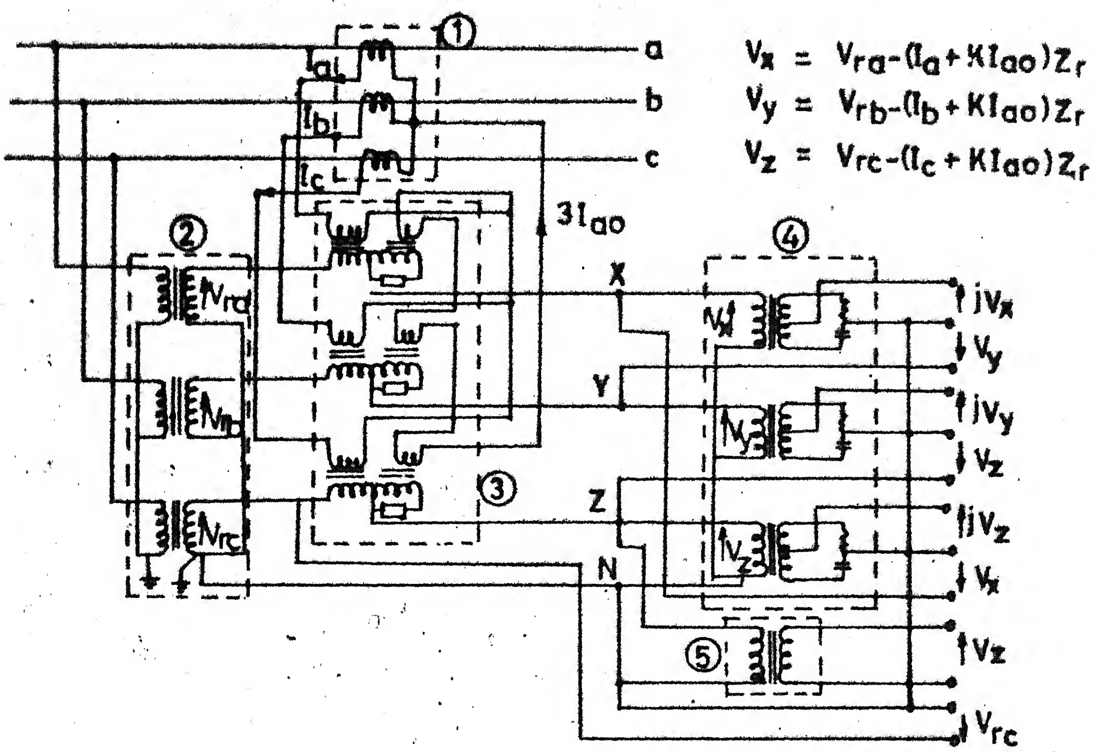
Using the first term only,

$$hy'_k = y_k - y_{k-1} \qquad \text{(AII.5)}$$

and with a second term

$$hy'_k = \tfrac{1}{2}(y_k - y_{k-2}) \qquad \text{(AII.6)}$$

Note that (AII.2) and (AII.3) for y'_k involve sample values at times later than t_k, whereas (AII.5) and (AII.6) do not.



① MAIN CURRENT TRANSFORMER
② VOLTAGE TRANSFORMER
③ TRANSACTOR UNITS
④ 90° PHASE SHIFTER
⑤ ISOLATING TRANSFORMER

FIG. 1 MEASURING CIRCUIT OF THE POLYPHASE DISTANCE RELAY

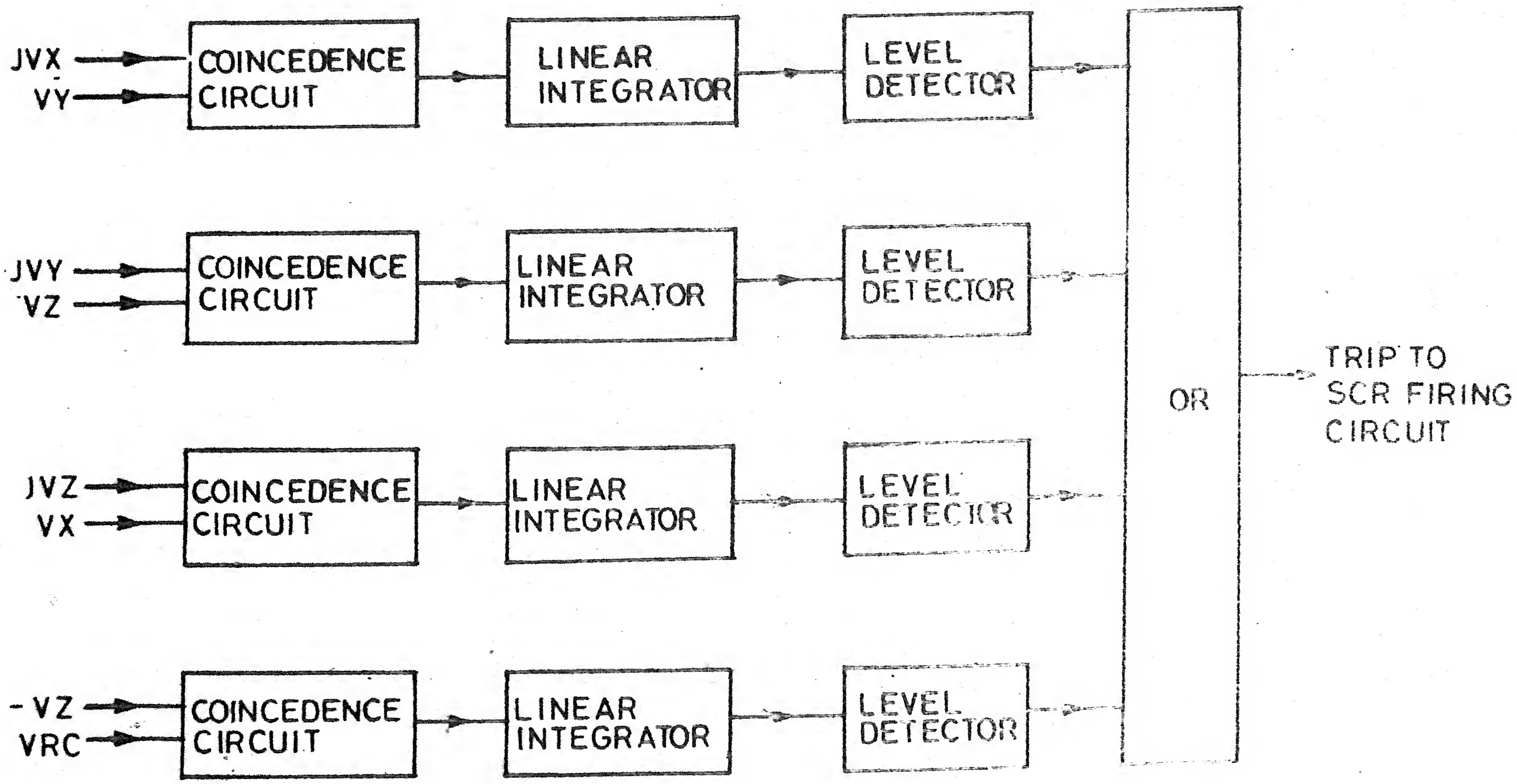


FIG. 2 BLOCK DIAGRAM OF THE PROPOSED POLYPHASE DISTANCE RELAY

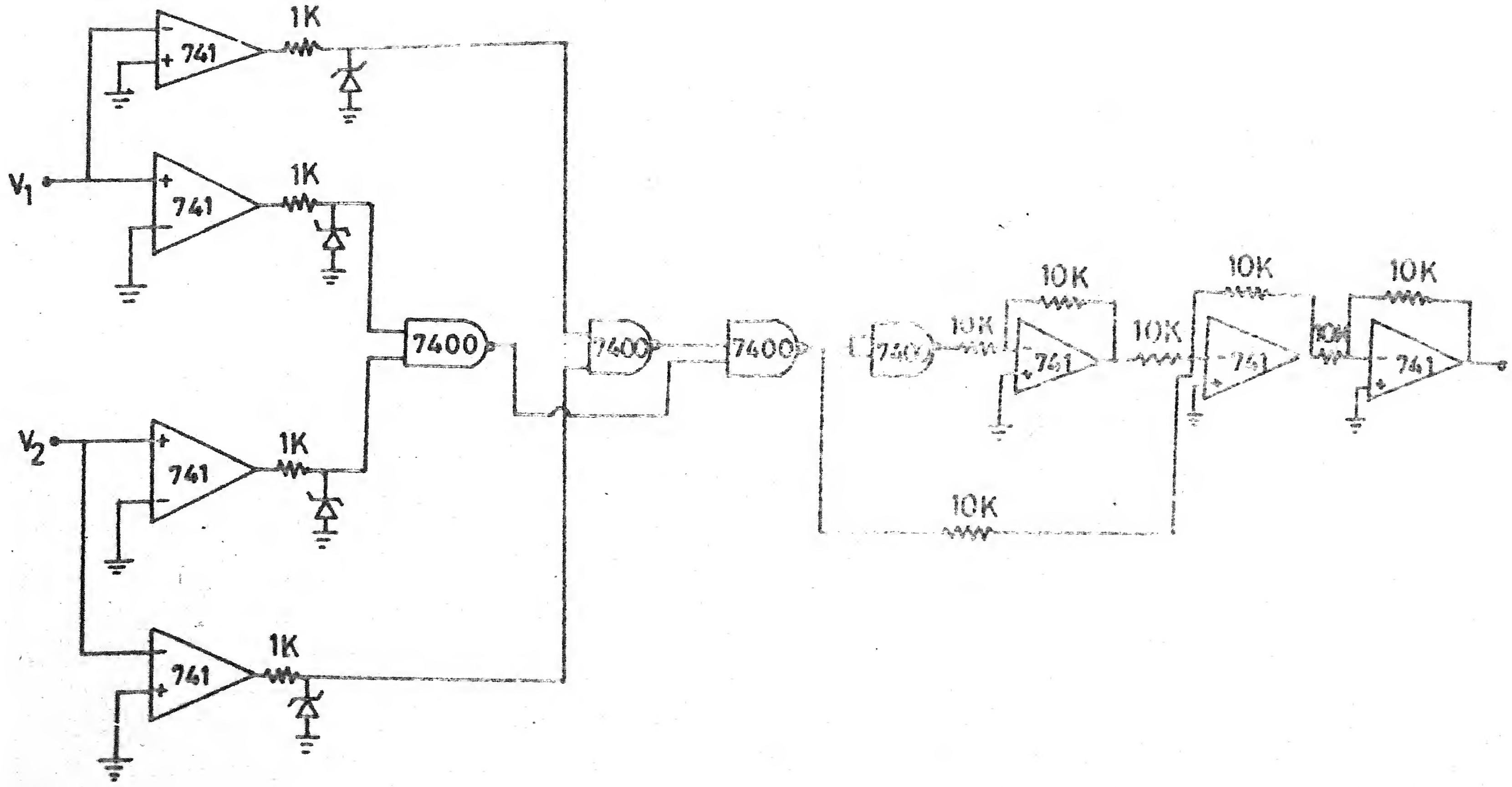
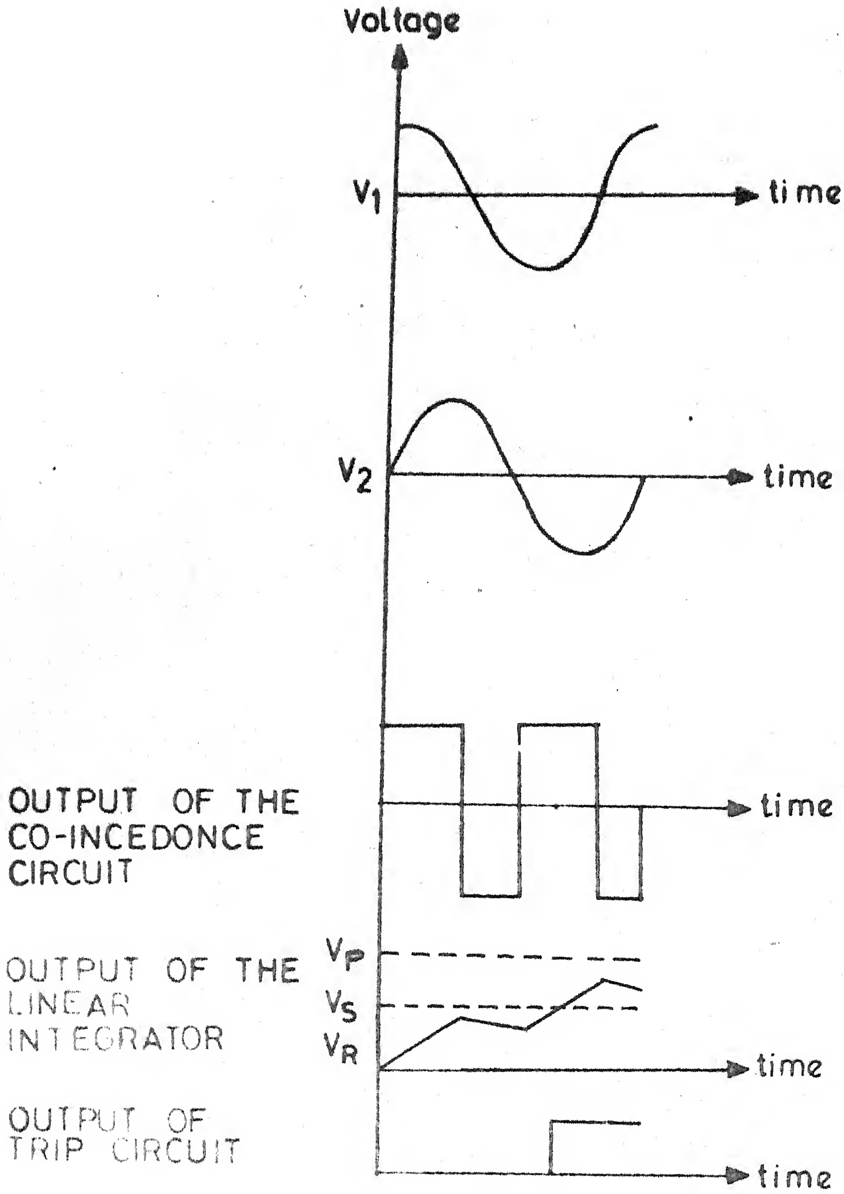


FIG. 3 COINCEDENCE CIRCUIT



V_P = INTEGRATOR EXCURSION LIMIT

V_S = SETTING OF THE LEVEL DETECTOR

V_R = RESETTING OF THE LEVEL DETECTOR

FIG.4 WAVE FORMS SHOWING THE RELAY OPERATION

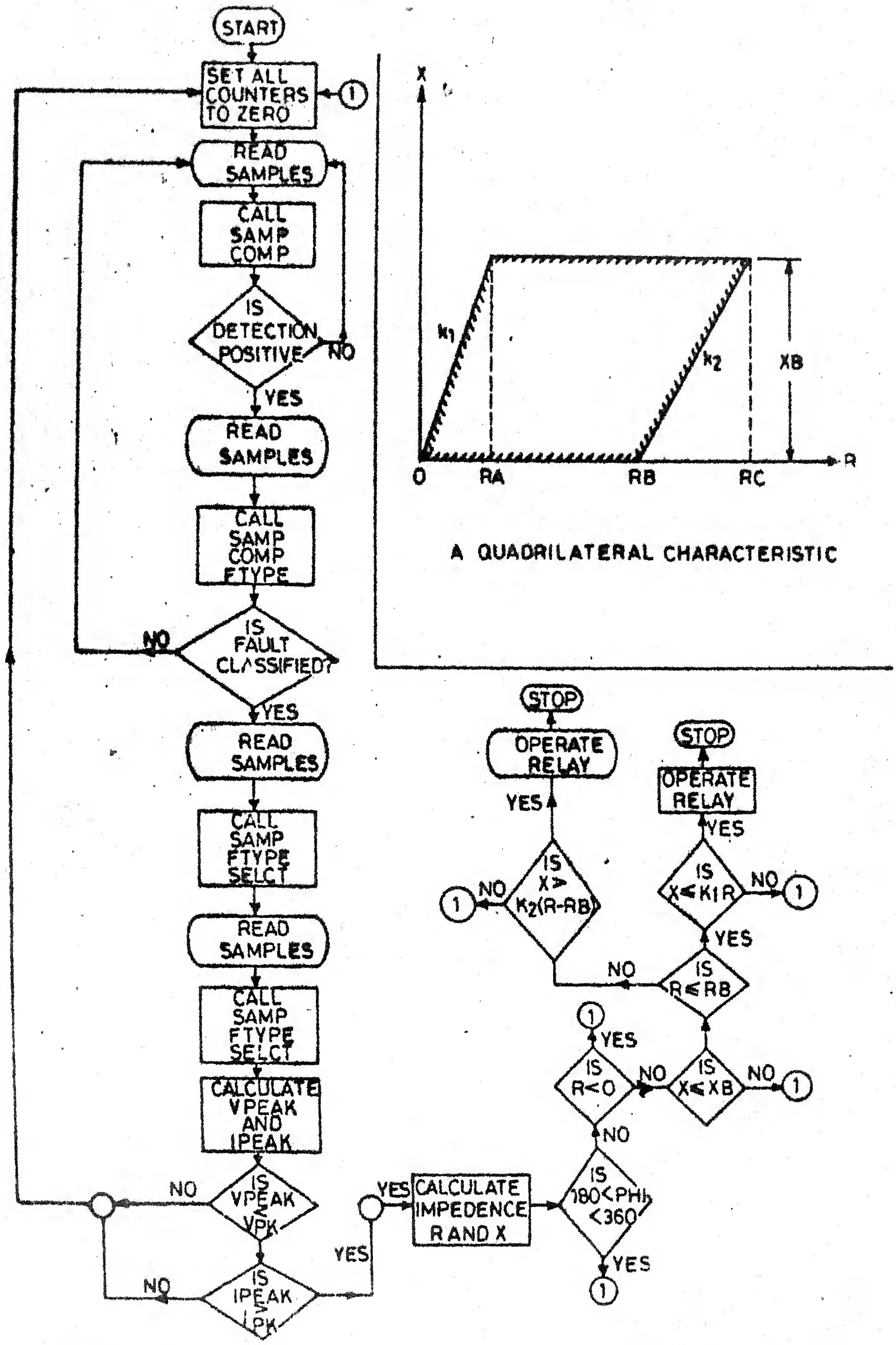


FIG 6 FLOW CHART OF THE PROPOSED RELAYING SCHEME.

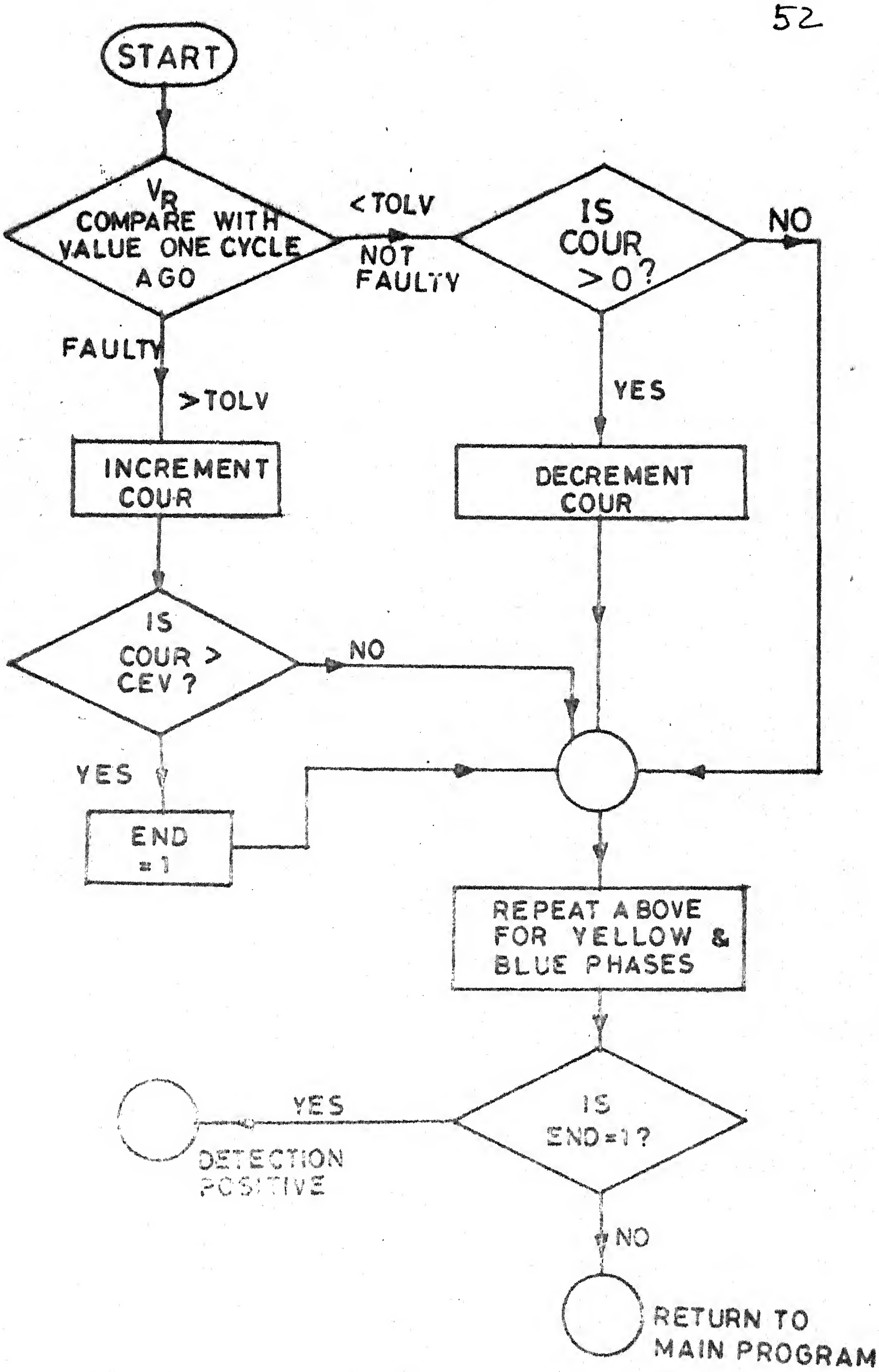


Fig. 7(a) SUBROUTINE COMP

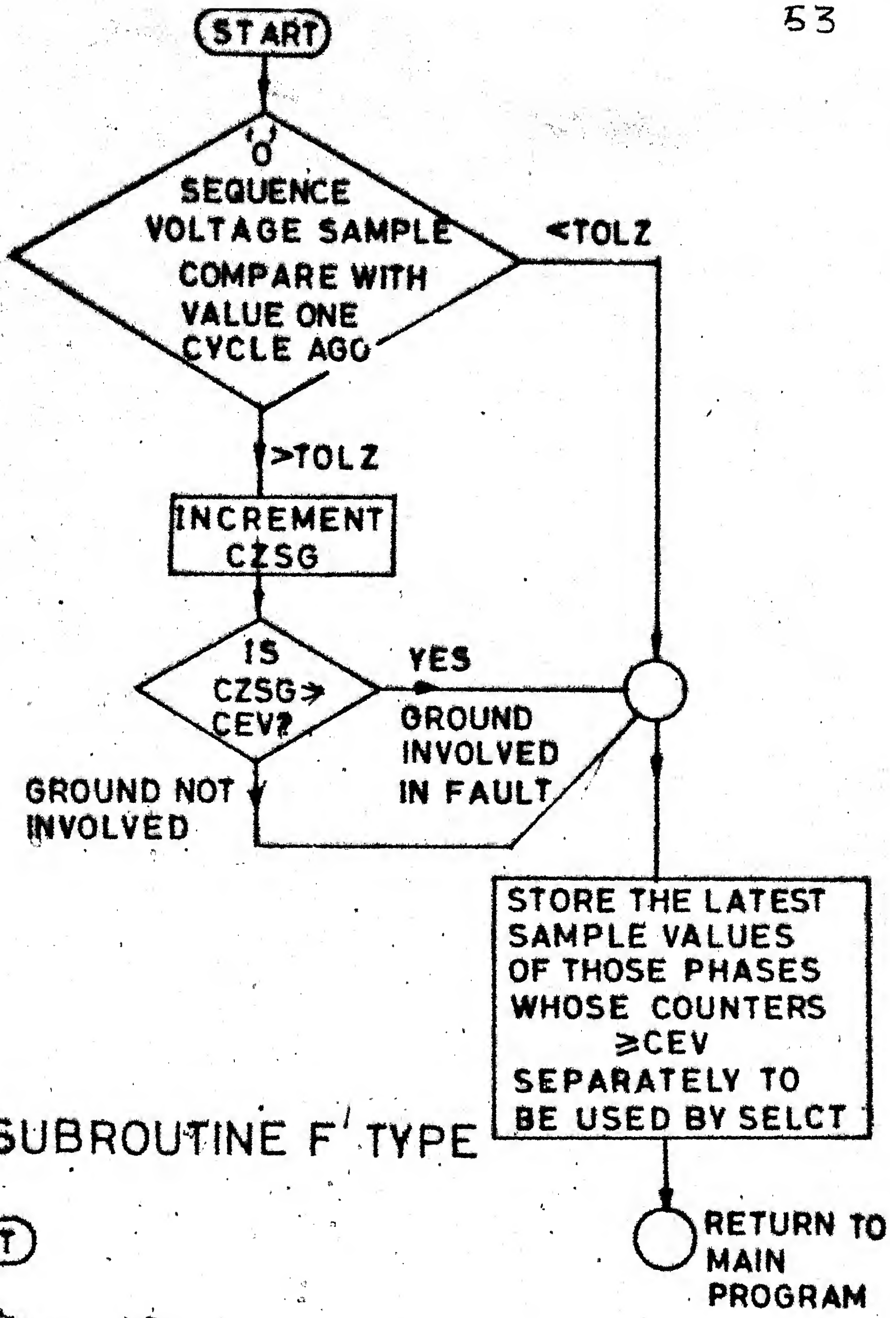


FIG.7(b) SUBROUTINE F' TYPE

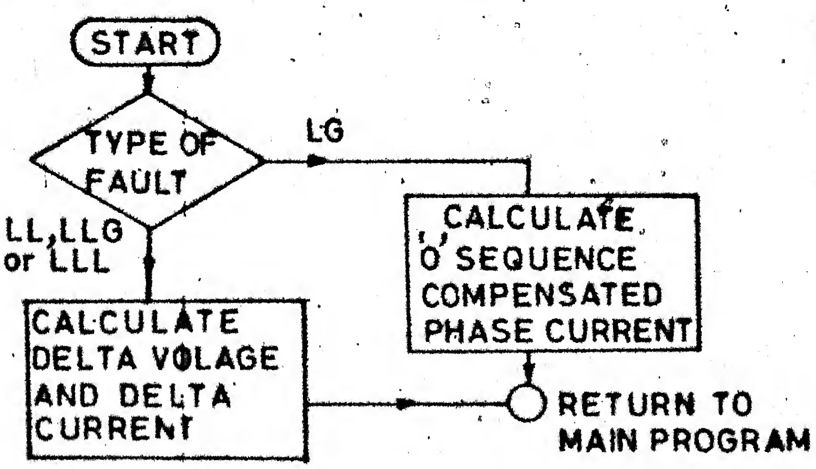
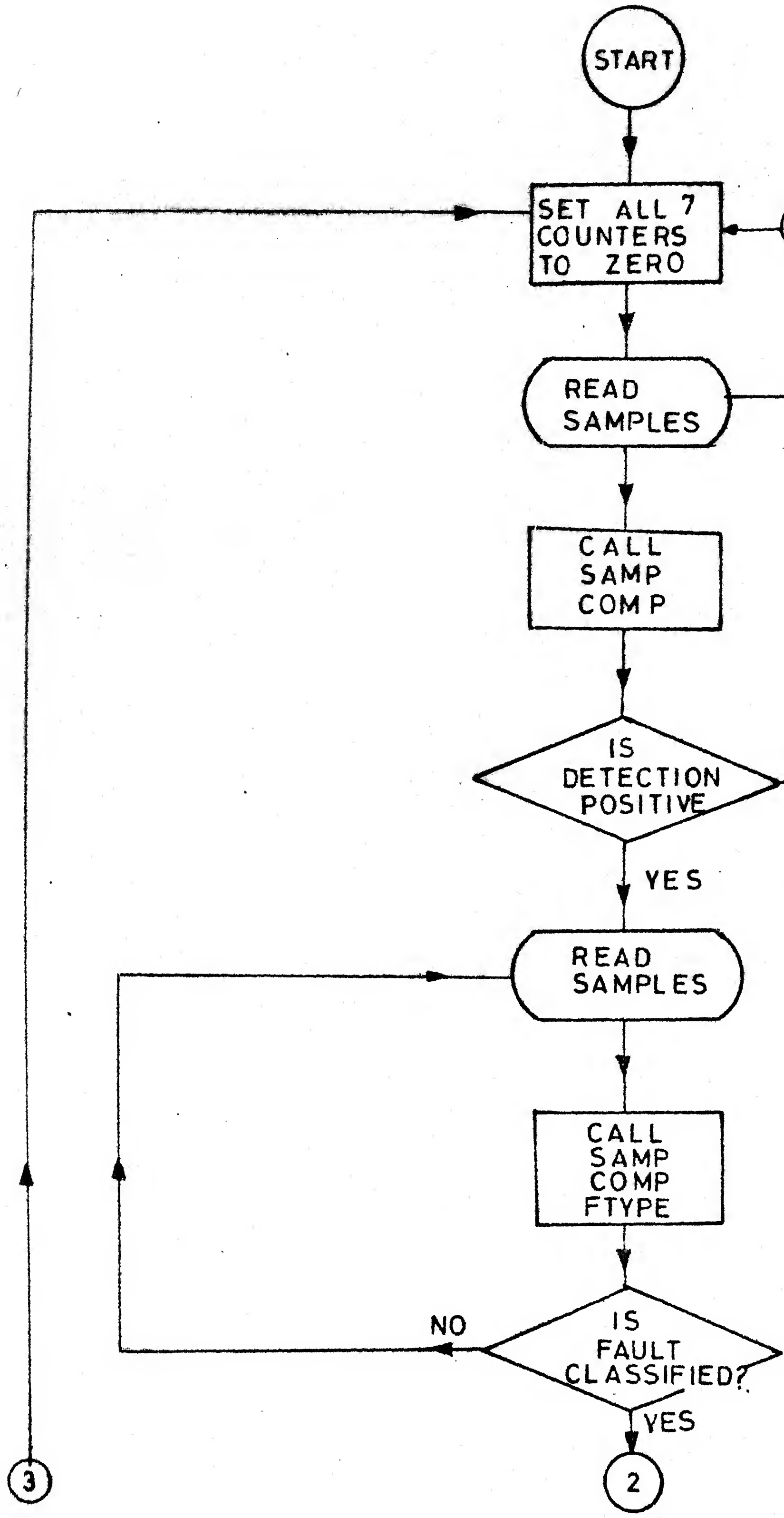


FIG.7(c) SUBROUTINE SELCT


START
SET ALL 7 COUNTERS TO ZERO
1
READ SAMPLES
CALL SAMP COMP
IS DETECTION POSITIVE
NO
YES
READ SAMPLES
CALL SAMP COMP FTYPE
IS FAULT CLASSIFIED?
NO
YES
3
2

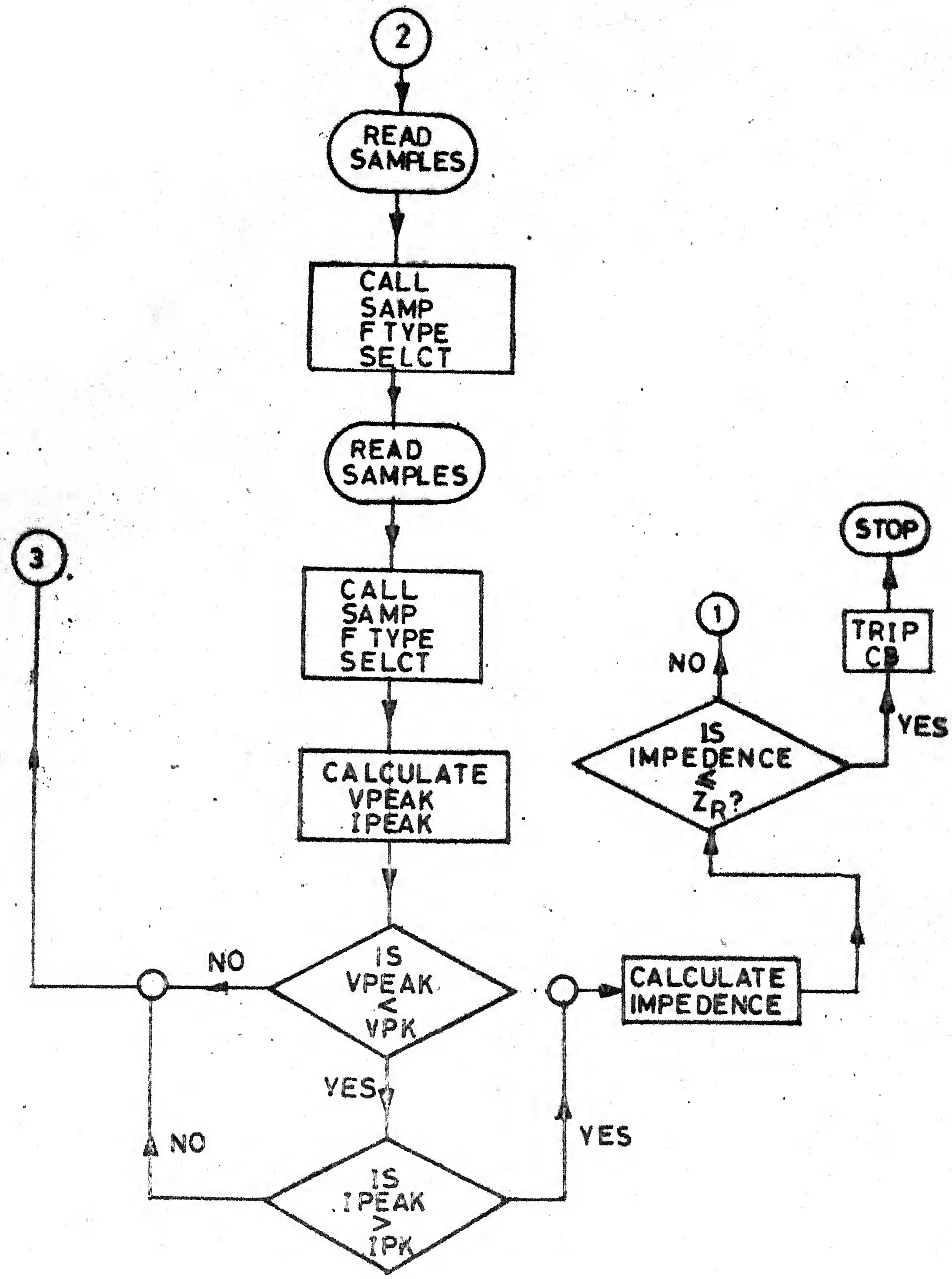


FIG.8 FLOW CHART OF PROPOSED 6 PHASE RELAYING SCHEME

```
C*************************************************************
C     3 PHASE RELAY WITH QUADRILATERAL CHARECTERISTICS
C*************************************************************
C**********************************************************************
C     NOF(1)=COUNTER FOR PHASE 1
C     NOF(2)=COUNTER FOR PHASE 2
C     NOF(3)=COUNTER FOR PHASE 3
C     NOF(4)=COUNTER FOR '0'SEQUENCE VOLTAGE
C     VUZ=PHASE VOLTAGE OR DELTA VOLTAGE DEPENDING UP ON THE TYPE OF
C     FAULT WETHER LG OR ANY PHASE FAULT RESPECTIVELY.
C     IUZ1=PHASE CURRENT OR DELTA CURRENT DEPENDING ON THE TYPE OF FAULT.
C**********************************************************************
      REAL K,IA,ITHETA,IUZ,VPEAK,IPEAK,IMP,IUZ1,IPEAK1,IT1
      INTEGER Z,W,U,P,R,S,THETA,P1
      COMMON V(6,40),AV(6,40),DV(40),DI(40),NOF(10),DI1(40)
      COMMON K(6,40),IA(6,40),VUZ(40),IUZ(40),ZV(40),ZI(40),IUZ1(40)
      OPEN(UNIT=20,DEVICE='DSK',FILE='LG.CDR')
      DO 222 J=1,36
      READ (20,223),(V(I,J),AV(I,J),IA(I,J),I=1,3)
223   FORMAT (//9(F10.7,3X))
222   CONTINUE
      ARA=.0636;ARB=.0669;ARC=.07;X=.369
      TYPE 65
65    FORMAT (//30X,'3 PHASE RELAY WITH QUAD CHAR TEST
65    1          FOR A LLG FAULT'//)
      TYPE 66
66    FORMAT (30X,30('-')//)
      W=314.0
406   DO 1 I=1,3
C     CALL TIME(M1)
1     NOF(I)=0
      NOF(4)=0
      DO 2 J=1,36
      P=J
      CALL SAMP(P)
      CALL COMP(P,IAF)
      IF(IAF.GE.1) GO TO 3
2     CONTINUE
3     P=P+1
22    CALL SAMP(P);CALL COMP(P,IAF);CALL FTYPE(P);IC=0
      DO 47 I=1,3;IF(NOF(I).EQ.3) IC=IC+1
      IF(IC.LT.2.AND.IC.NE.0) GO TO 3
47    CONTINUE
C     TYPE 55
```

```
55      FORMAT (///20X,'ALL VALUES IN PER UNIT'//)
        P=P+1
        CALL SAMP(P)
        CALL FTYPE(P)
        CALL SELCT(P)
        P=P+1
        CALL SAMP(P)
        CALL FTYPE(P)
        CALL SELCT(P)
        P=P+1;CALL SAMP(P);CALL FTYPE(P);CALL SELCT(P)
        H=1./1800.
        CALL TIME(N1)
        DV(P-1)=(VUZ(P)-VUZ(P-2))/(2.*H)
        DI(P-1)=(IUZ(P)-IUZ(P-2))/(2.*H)
        DI1(P-1)=(IUZ1(P)-IUZ1(P-2))/(2.*H)
        VPEAK=SQRT((VUZ(P-1)**2)+DV(P-1)**2/W**2)
        IPEAK=SQRT((IUZ(P-1)**2)+DI(P-1)**2/W**2)
        IPEAK1=SQRT((IUZ1(P-1)**2)+DI1(P-1)**2/W**2)
        IF ((ABS(VPEAK)).GE.1.414) GO TO 406
        IF((ABS(IPEAK)).LE.1) GO TO 406
        WV=W*VUZ(P-1);WI=W*IUZ(P-1)
        VTHETA=ATAN2(WV,DV(P-1))
        ITHETA=ATAN2(WI,DI(P-1))
        IT1=ATAN2(W*IUZ1(P-1),DI1(P-1))
        VT=VTHETA*180./3.1416
        AIT=ITHETA*180/3.1416
        ZTHETA=VTHETA-IT1
        IMP=VPEAK/IPEAK1
        PHI=ZTHETA*180./3.1416
        IF(PHI.LT.0.0) GO TO 406
        AR1=IMP*COSD(PHI);X1=IMP*SIND(PHI)
        AK1=X/ARA;AK2=X/(ARC-ARB)
        IF(AR1.LT.0.0) GO TO 406
        IF(X1.GT..5) GO TO 406
        IF(AR1.LE.ARB.AND.X1.LE.(AK1*AR1)) TYPE 100
        IF(AR1.GT.ARB.AND.X1.GE.(AK2*(AR1-ARB))) TYPE 100
        CALL TIME(N2)
        TYPE 45
45      FORMAT (///20X,'PEAK VOLTAGE',5X,'PEAK CURRENT',
        1        5X,'IMPEDENCE',5X,'PHASE ANGLE(DEGREES)',
        1        5X,'VOLT ANGLE',5X,'CURRENT ANGLE'//)
        TYPE 46,VPEAK ,IPEAK,IMP,PHI,VT,AIT
46      FORMAT (20X,F7.5,10X,F7.3,10X,F7.5,10X,F7.1,16X,F7.3,10X,F8.3//)
        TYPE 35
```

```
35    FORMAT (20X,'COUNTER PH1',5X,'COUNTER PH2',5X,'COUNTER PH3',
      1       5X,'0 SEQ COUNTER'//)
      TYPE 36,((NOF(I6),I6=1,4))
36    FORMAT (20X,3(I3,15X),1X,I3//)
      TYPE 17,P
17    FORMAT (//40X,'NO OF SAMPLES READ =',2X,I3//)
      IF (PHI.GE.180.0.AND.PHI.LT.360.) GO TO 406
      IF(IMP.GT.1) GO TO 406
      TYPE 100
100   FORMAT(/////,40X,'TRIP CKT BREAKER')
      IF(NOF(4).GE.4) TYPE 44
44    FORMAT(//40X,'GROUND FAULT DETECTED'//)
      GO TO 101
      GO TO 101
101   NR=N2-N1;TYPE 333,NR
333   FORMAT(//20X,'OPERATING TIME OF THE RELAY =',1X,I3,1X,'ms'//)
      STOP
      END
      SUBROUTINE SAMP(P)
C***************************************************************************
THIS ROUTINE CALCULATES THE '0'SEQUENCE VOLTAGES AND CURRENTS.
C***************************************************************************
      REAL K,IA,ITHETA,IUZ,VPEAK,IPEAK,IMP,IPEAK1
      INTEGER Z,W,U,P,R,S,THETA,P1
      COMMON V(6,40),AV(6,40),DV(40),DI(40),NOF(10),DI1(40)
      COMMON K(6,40),IA(6,40),VUZ(40),IUZ(40),ZV(40),ZI(40),IUZ1(40)
      ZV(P)=((V(1,P)+V(2,P)+V(3,P)))/(3.)
      ZI(P)=((IA(1,P)+IA(2,P)+IA(3,P)))/(3.)
      RETURN
      END
C***************************************************************************
      SUBROUTINE FTYPE(P)
C     THIS ROUTINE SETS THE '0'SEQUENCE COUNTER AND ALSO PREPARES ALL
C     THE COUNTERS FOR ROUTINE 'SELCT'
C***************************************************************************
      REAL K,IA,ITHETA,IUZ,VPEAK,IPEAK,IMP,IUZ1,IPEAK1
      INTEGER Z,W,U,P,R,S,THETA,P1
      COMMON V(6,40),AV(6,40),DV(40),DI(40),NOF(10),DI1(40)
      COMMON K(6,40),IA(6,40),VUZ(40),IUZ(40),ZV(40),ZI(40),IUZ1(40)
      INTEGER T
      DO 22 T=1,3
      IF(NOF(T).GE.4) GO TO 23
      K(T,P)=0.0
      GO TO 22
```

```
22    CONTINUE
      P5=P-5
      DO 21 R=P5,P
      IF(ABS(ZV(R)-ZV(R-1)).LT.0.02) GO TO 21
      NOF(4)=NOF(4)+1
21    CONTINUE
      RETURN
      END
C*****************************************************************************
      SUBROUTINE SELCT(P)
C     SELECTS WHICH TWO OF THE 3 PHASES OR GROUND ARE INVOLVED IN A FAULT
C     AND TO DERIVE EQUIVALENT SINGLE PHASE RELAYING QUANTITY
C*********************************************************************
      REAL K,IA,ITHETA,IUZ,VPEAK,IPEAK,IMP,IUZ1,IPEAK1
      COMPLEX Z1,Z2,Z0,PK1
      INTEGER Z,W,U,P,R,S,THETA,P1
      COMMON V(6,40),AV(6,40),DV(40),DI(40),NOF(10),DI1(40)
      COMMON K(6,40),IA(6,40),VUZ(40),IUZ(40),ZV(40),ZI(40),IUZ1(40)
      DIMENSION B(6,40),A(6,40)
      Z1=(.0669,.369);Z0=(.3678,.96)
      PK1=(Z0-Z1)/Z1
      PK=CABS(PK1)
      Z=0
      DO 25 U=1,3
27    IF(K(U,P).NE.0.0) GO TO 28
      GO TO 25
28    Z=Z+1
      A(Z,P)=K(U,P)
      B(Z,P)=IA(U,P)
25    CONTINUE
      IF(Z.GE.2) GO TO 100
      IF(Z.EQ.1.AND.NOF(4).GT.0) GO TO 60
      GO TO 61
60    VUZ(P)=A(1,P)
      IUZ(P)=B(1,P)
      IUZ1(P)=B(1,P)+(PK*ZI(P))
      GO TO 61
100   VUZ(P)=A(1,P)-A(2,P)
      IUZ(P)=B(1,P)-B(2,P)
      IUZ1(P)=IUZ(P)
61    RETURN
      END
C*****************************************************************************
```

```
      SUBROUTINE COMP(P,IAF)
C     DOES THE CYCLE BY CYCLE COMPARISON OF VOLTAGE SAMPLES
C*****************************************************************************
      REAL K,IA,ITHETA,IUZ,VPEAK,IPEAK,IMP,IUZ1,IPEAK1,IT1
      INTEGER Z,W,U,P,R,S,THETA,P1
      COMMON V(6,40),AV(6,40),DV(40),DI(40),NOF(10),DI1(40)
      COMMON K(6,40),IA(6,40),VUZ(40),IUZ(40),ZV(40),ZI(40),IUZ1(40)
      IAF=0
      DO 20 M=1,3
      IF((ABS(AV(M,P)-V(M,P)).LT.0.05)) GO TO 19
      NOF(M)=NOF(M)+1;GO TO 20
19    IF(NOF(M).NE.0) NOF(M)=NOF(M)-1
20    CONTINUE
      DO 2 I=1,3
      IF (NOF(I).GE.4) IAF=IAF+1
2     CONTINUE
      RETURN;END
```